Impact Of Redesigning A Large-Lecture Introductory Earth Science Course To Increase Student Achievement And Streamline Faculty Workload

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ABSTRACT

A Geological Perspective is a general education survey course for non-science majors at a large southwestern research extensive university. The class has traditionally served 600 students per semester in four 150-student lectures taught by faculty, and accompanied by optional weekly study groups run by graduate teaching assistants. We radically redesigned the course to 1) improve student learning and, simultaneously, 2) reduce faculty effort. Previously optional study groups were replaced by weekly mandatory break-out sessions, run largely by undergraduate peer mentors. Twice weekly, lectures are brief with a large portion of class time allocated to active learning in small groups. Completing quizzes on-line reduced grading and allowed students more flexibility. Evaluation of the redesign (mixed methods, quasi-experimental, two-group, pre-test-post-test, multiple-measures study design) revealed no significant improvements in learner outcomes insofar as the instruments could measure. However, qualitative results reveal that overall students greatly valued their learning experience under the redesign. In addition, the redesign reduced the departmental cost of the class offering per student by more than half.

Keywords: science education; large-enrollment lectures; general education

INTRODUCTION

Large-enrollment, undergraduate introductory geoscience survey course offerings are common at colleges and universities, which require non-science majoring undergraduates to take general education science survey courses as part of their degree program. A prevalent notion supporting the teaching of this course is that college and university graduates across all academic disciplines, including future K-12 teachers, need some exposure to the nature of science and its impact on society. As such, introductory science courses are widely regarded as an important component of the college and university larger portfolio of course offerings.

Sheila Tobias argues that introductory science survey courses have a widespread, tacit stigma among students as boring, vocabulary-laden, memorization courses with little, if any, relevance to real life (Tobias, 1994). In much the same way, many professors proffer that these courses are impossibly challenging to teach well, are filled with apathetic students, rarely result in high student course ratings, and suffer from limited infrastructure support so that graded assignments that probe higher order knowledge and skills, particularly those including student writing, are rarely used (Slater & Adams, 2002). Given such a resoundingly negative starting point, one might wonder if any large-enrollment, introductory geoscience survey course, regardless of the underlying content or pedagogical approach, is able to achieve any success at all.

One approach to building a successful introductory science survey course is to purposefully construct them around themes of learner-centered, active intellectual engagement by relying on students' proclivity toward social interactions. The utility of active engagement and social discourse as engaging teaching strategies has a long and rich history in the science education literature, if not often employed. Many of the educational notions of learner-centered teaching, such as "social cognition," "community of learners," "collaborative learning," "cooperative learning," and "problem-based learning" represent a natural progression of the work began by Lev Vygotsky in the early 1900's and continued by others in the 1960's. With such a long history, it isn't surprising that the term "active engagement" can take on a wide variety of meanings in different venues. This lack of specific definition is appropriate, as there are many strategies by which one may engage students to interact with content, both cognitively and affectively. For the purpose of this the present study, we have chosen to define active intellectual engagement as any instructional method that engages students in the learning process, in which the student must participate in meaningful learning activities and think about what they are doing. While this might initially seem to be a fairly vague definition, it should stand sufficiently in stark contrast to much of traditional instruction which involves uninterrupted professor-centered lecture, teacher-talk, and assignments that are rote in nature.

Bonwell and Eison (1991) summarize the literature on active learning and enthusiastically argue that it leads to better student attitudes and improvements in students' thinking and writing. As part of their position, they cite evidence from McKeachie (1972) that discussion, or social discourse, surpasses traditional lectures in facilitating retention of material, motivating students for further study, and developing thinking skills. In much the same vein, Felder and his colleagues (2000) specifically include active learning in their listing of recommendations of teaching methods that work. Many of these are easily adaptable to the large-lecture setting, if done purposefully, as described in detail elsewhere by Slater and his colleagues (Slater, 2008; Slater, Prather, & Zeilik, 2006; Adams & Slater, 2004), among other authors.

Moreover, teaching strategies that engage students in social discourse have a long history of successful use in classrooms. Probably the most often cited is an exhaustive review of the literature on collaborative learning. Johnson, Johnson, and Smith (1998) found that 90 years of research indicated that collaborative work improves learning outcomes. To add even further evidence, a review completed by Springer, Stanne, and Donovan (1999) found similar results by looking at 37 studies in science, technology, engineering and mathematics. These gains include content knowledge, student self-esteem, attitudes, and students' perceptions of the social support in the classroom. These reviews looked at the size of the gains relative to each outcome, disaggregated to look at "collaborative versus individualistic" studies and "collaborative versus competitive" studies. In both cases, the sizes of the gains were significant, with the largest impacts found in studies comparing the positive effects of collaborative treatments to far less effective competitive treatments. In addition, they found that the biggest impacts were seen when instructors employed a moderate, rather than large, amount of collaborative work in their instruction. Their review also indicated that collaborative work enhanced retention in science, technology, engineering, and mathematics (STEM) education programs, particularly for students from traditionally unrepresented groups. Taken together, we view this as substantial evidence that leaning on students' social discourse should be an effective approach to building modern STEM courses.

Similarly, there have been a vast number of studies conducted on active engagement. For example, education researchers have convincingly argued that there are measurable differences in the conceptual models of motion between students who received traditional, largely lecture-based instruction in physics, and those who were in courses that uses active engagement as an instructional strategy. In these studies, active engagement was defined as nearly anything that was not lecture, including "clicker" questions, labs, and think-pair-share questions (Hake, 1998; Laws et al., 1999; Redish et al., 1997; Thornton & Sokoloff, 1988). The studies conducted by Redish and his colleagues at Maryland, and Laws and her colleagues at Davidson, suggested that the impact of active engagement was not due to increased time on task, but by the nature of the tasks themselves. Furthermore, student engagement was particularly effective in addressing student misconceptions in physics (Redish et al., 1997). Francis, Adams and Noonan (1998) found that the difference between control and treatment groups was still measureable one to three years later and that there was only a scant decay in achievement over that time. These bode well for instructors wishing to use a theme of active engagement in their instruction.

Perhaps what could be most surprising is that very small efforts toward actively engaging students can reap appreciable results. In 1987, Ruhl, Hughes, and Schloss (1987) found that simply pausing during a lecture to allow students to consolidate their notes, for three times, for two minutes at each pause, increases student learning. These researchers found that when an instructor paused for longer periods of time, ranging between 12 and 18 minutes, and allowed students to rewrite notes or discuss the material with peers, without any interaction with the instructor, student learning increased, as measured immediately after instruction and on assessments 12 days after the last lecture. Other interventions might be as simple as allowing students to think or talk about what they know about a topic before formal instruction begins.

In a variety of contexts, with a wide variety of participants, studies have repeatedly shown that actively engaging students in the material increases their learning. The details of why and how this occurs may not be as important for the day-to-day classroom instructor who wants to improve learning as it is for the educational researcher trying to understand the underlying cognitive issues of the learner, but this seems to be one of the most useful results for building courses that have a better chance of increasing students' learning.

If creating learner-center, active learning environments are so vitally important to an educated citizenry, yet simultaneously relatively uncommon at the college and university level, then this situation begs some important questions for classroom instructors. First, can large-enrollment, introductory geoscience courses be modified to reflect contemporary pedagogy that students and professors value? Second, can this be accomplished while reducing institutional costs and faculty effort?

In order to pursue this question, a large-lecture, general education science class entitled *A Geological Perspective*, normally consisting of three 50-minute lectures per week, with traditional textbook and optional study sessions led by graduate students, was replaced by two weekly 50-minute interactive lectures and one weekly 50-minute required Socratic-tutorial ('break-out") session focusing on collaborative learning, led by graduate assistants and undergraduate peer mentors. In other words, the faculty used a reformed teaching framework of learner-centered education, based on the learner-centered notion of Slater and Adams (2002) to overhaul the large-enrollment, introductory geoscience course to include interactive lectures, just-in-time on-line quizzes, a next-generation textbook, and weekly collaborative learning break-out sessions. The class load for faculty then consists of 600 students taught in four separate 150-student lectures. The 600 students in the class are all non-science majors, taking the class to fulfill general education science requirements. Over 75% of the students enrolled are freshman, with the other 25% including all other undergraduate levels. Less than 10% are honors students. Demographically the class generally represents the undergraduate population at the university with ~8% minorities, with roughly 9% of the minority students being of Mexican descent. The details of the course redesign are described below.

REDESIGN MODEL

The course redesign was supported by a state higher education grant. The departmental geosciences team decided on a replacement type redesign, in which some aspects of the course would be replaced with new or modified ways of teaching and/or completing and submitting work. The team replaced one lecture period a week with a mandatory break-out session led by undergraduate peer mentors and/or a graduate teaching assistant (GTA). Peer mentors are undergraduate students who have successfully completed the course in a previous semester with a high grade and have been invited by the instructor to return as part of the teaching team the following semester. The redesign reduces faculty weekly classroom hours from three to two, and gives students an opportunity each week for more personalized attention in a small group setting. We also replaced weekly quizzes normally submitted to faculty in class with low stakes weekly reading quizzes submitted on-line via our institution's course management system, D2L (*Desire 2 Learn*). Importantly, we chose to have the on-line reading quizzes due before the chapter material was covered in class, increasing student preparation for lecture. The on-line quizzes allow students more flexibility in when and where they work on quizzes, provide immediate feedback on how they did, and reduce the time faculty members spend grading weekly work. Additionally, the majority of students are familiar with D2L, as they have used it, or are using it, for university classes.

Traditional lectures did previously include short activities incorporated into some class periods. In this setting, however, it proved difficult to provide much one-on-one help as students grappled with questions. Traditional class time was therefore replaced with lectures including short (~10 minutes) mini-lectures, in which the instructor delivers key concepts, alternating with learner-centered activities such as think-pair-share questions or short writing assignments. Class periods end with a summary of the key concepts learned that day. Students spend much of the class period in small groups working on activities tied to the reading and the lecture material. Questions may involve writing (short answers) and answering higher level synthesis questions, or may be conceptually focused multiple choice questions. These in-class assignments are graded by the instructors. During these activities the instructor, along with GTAs and peer mentors, circulate throughout the classroom and actively pose and address questions with the students. In this way students have a better chance of frequently interacting with their fellow students, peer mentors, GTAs, and the instructor. Finally, we increased the number of undergraduates in our peer mentoring program, and strengthened the quality and quantity of training these preceptors receive prior to teaching the class. This allows us to replace several of our most costly GTAs with undergraduate peer mentors, which produced a substantial reduction in cost.

The new version of *A Geological Perspective* has four lecture sections of 150 students each that meet twice weekly for 50 minutes, and 24 weekly 50 minute break-out sessions of ~25 students each. Activities and assignments are consistent throughout all lectures and break-out sessions. All GTAs and undergraduate peer mentors receive some training by a member of our University Teaching Center during the course of the semester. As an ongoing effort, GTAs and peer mentors meet weekly with class instructors.

During lecture, students are required to be significantly more engaged in the course than in the past. A typical 50 minute lecture period involves about 20-30 minutes of interactive work time in a small group, facilitated by the instructor and GTAs, punctuated by mini-lectures. Points are awarded for submitted work resulting from the small group interactions, and replace attendance points. The in-class activities are essential to student success in the class, and to reflect this they account for roughly 12% of their total course grade. These in-class activities also serve as additional opportunities to practice for exams, as the questions probe their knowledge of key concepts that will be covered on exams and are intended to help increase students' metacognition. A student who only attends exams and completes on-line quizzes will not be able to earn an A in the class, as they will be missing points that are accumulated from in-lecture activity and break-out session activity participation.

Once a week, students meet in small (~25 students) mandatory break-out sessions led by GTAs and/or undergraduate peer mentors. Break-out sessions are held at the end of each week, and there students can ask questions about lecture material and get help on assignments that are turned in at the end of their break-out session. The assignments are carefully tailored to make students practice skills and apply concepts that were introduced that week in lecture. The questions used on these assignments are meant to intellectually push students to think beyond terms and facts, and apply critical thinking and problem solving skills. In essence, the break-out sessions are their chance to test their abilities and receive formative feedback before having to answer such questions on an exam. Students often feel more comfortable approaching their TA or peer mentor, and this weekly session gives them face time with their GTAs and peer mentors in a less formal setting. For example, instructors commonly contact students who have done poorly on the first exam and encourage the student to meet with the GTA/peer mentor or instructor. Anecdotal evidence indicates that students are much more likely to meet with their GTA or peer mentor. In addition, students work collaboratively with each other, thereby further benefiting from peer teaching and learning. GTAs and peer mentors grade weekly break-out session assignments.

Because weekly reading quizzes are submitted on-line, students receive automated formative feedback instantly. Quizzes are graded by the software, and after a given quiz period has ended students can view their results, all the correct answers, and pre-programmed instructor comments and tutoring on common mistakes. Most on-line quiz questions come directly from the textbook (*The Good Earth* by McConnell et al.) and its associated materials, and have been designed to probe a deeper level of knowledge, not just memorization of facts. Instructors post more in-depth discussions about "common mistakes" on the course management website with their explanations for why certain answers were incorrect and what answers they were looking for. Instructors have the ability to make feedback available to students anytime on the course website, or can choose to use lecture time to cover especially confusing concepts. Moreover, students are able to see their grades any time on the course management system website to monitor their own progress. Instructors post milestones for studying and important deadlines to keep students on track. Recognizing that the large-enrollment classroom is a challenge for personalized learning, most instructors have chosen to learn the names of the 150 students in each lecture. They do this through office hour meetings, having students fill out a profile on D2L with a photo if they are willing, personalized email messages, and assigned seating in the lecture hall. As previously noted, instructors also use early intervention with students who are doing poorly in the course. For example, students who routinely miss class in the first two weeks are contacted via email, and asked if they intend to remain in the class. If they respond that they do, they are strongly encouraged to begin attending regularly, and if they cannot commit to this they are encouraged to consider dropping the course. In at least one case of this type of intervention, a student's advisor from another college at the university sent a personal email to their *Geologic Perspective* instructor thanking them for not letting the student "fall through the cracks."

LEARNING MATERIALS

The materials we use are as follows: Textbook – *The Good Earth*: *Introduction to Earth Science*. Considered somewhat *avant guard*, this text is highly innovative and has been specifically written for introductory earth science for non-science majoring undergraduates. It also lends itself well to the large lecture setting, providing activities to be done during the lecture and many additional interactive on-line assignments. The authors include college professors who have spent years teaching large lecture classes, their colleagues in education who are experts in pedagogy, and a cognitive psychologist who studies how people learn. *The Good Earth* is designed to facilitate inquiry-based active learning and focuses on student-centered teaching methods. The activities are set up for large classes and encourage the use of small groups in which students can interact and learn from each other.

Through the on-line course management system (currently based on *D2L Desire-2-Learn*, an open source *WebCT/Blackboard* look-alike), students view announcements and class material (such as class outlines or notes), frequently monitor their progress, see their grades and feedback, attend virtual office hours, participate in on-line tutorials, post messages and questions to each other and their instructors, form study groups, complete and submit quizzes and assignments, view animations and video clips, and be reminded of assignments and deadlines. Although the text also comes with a classroom participation system (cps) in which students can respond to questions posed in class via hand held clickers, we chose not to use clickers as we prefer using color coded, lettered cards that students hold up in response to a question posed by the instructor. Although these responses cannot be auto-graded as clicker responses can, an instructor can still make an immediate, rough assessment of the percentage of the class that is actively engaged, and the percentage that understand the concept, and make a decision about whether or not to proceed or go back and re-teach the concept in a different way.

COST REDUCTION STRATEGY

A Geological Perspective has a stable enrollment. In order to produce cost savings we 1) reduced the number of hours each faculty member devotes to preparation, grading and classroom time, and 2) reduced the number of graduate teaching assistants involved in the course and replaced them with undergraduate peer mentors. Common to many institutions, faculty members are often reluctant to teach such large courses due to the time commitment required for preparation, grading, and teaching. By replacing one of our weekly lecture periods with break-out sessions, faculty reduced classroom time by one hour per week. In addition, all lecture materials have been developed by one instructor. While faculty members often personalize the lecture materials, they are not required to generate their own lectures or lecture activities. Because weekly quizzes are submitted on-line, faculty grading time is significantly reduced. Finally, we primarily use undergraduate peer mentors to teach weekly break-out sessions, reducing the number of GTAs needed. Using undergraduates greatly reduces cost as they volunteer to be part of the peer mentor program in exchange for three units of academic credit. Our peer mentor program is a well-established, highly regarded program in which undergraduates learn about teaching methods from our instructors, guest speakers, and teaching experts at our institution. Peer mentors also attend a weekly meeting with the course instructors in which they learn about the assignments they are helping to facilitate, and how best to help students learn the material and complete their work. Using peer mentors is extremely valuable to the educational experience of our students. The savings in time devoted to class preparation have been used by faculty for other priorities, including research and teaching higher level courses.

TIMELINE

Our first pilot semester was spring of 2008. The first lecture class period outlined all aspects of the course and what it would take to be successful, including the highly active nature of the lectures and the points earned for completing in-class activities. Faculty made it clear to students that if they missed three consecutive classes in the first few weeks they would be administratively dropped from the class. During the pilot semester we gave the *Geoscience Concept Inventory* (Libarkin & Anderson, 2005) as a pre-and post-test to monitor learning gains. We also gave the *Attitudes Toward Science* (Weinburgh & Steele, 2000) survey at the end of the semester. Using the results from these measures, we modified the class for full implementation starting in the fall semester of 2008, and continuing today. Redesigning the course was done with the assumption that it would continue in future semesters with modifications as needed to enhance the student learning experience and continue to keep costs low, which it has.

EVALUATION DESIGN AND RESULTS

In an effort to evaluate the course overhaul described above, we adopted a mixed methods, quasi-experimental, two-group, pre-test-post-test, multiple-measures study design. On the quantitative side, we conducted pre-test and post-test administrations of the *Geosciences Concept Inventory 1.0* (Libarkin & Anderson, 2005), the *Attitudes Toward Science Instrument* (Weinburgh & Steele, 2000), and an *ad hoc* inductive analysis of exam items common to before and after the course redesign. To gain further insight, we conducted an analysis of 14 hours of focus group interview transcripts to look for recurrent themes in student experiences and provide explanatory power to the quantitative instruments.

Quantitative Results

The *Geosciences Concept Inventory* (GCI v1.0) was given as a pre-test/post-test to students in the pre-modified course and the reformed course to compare student learning in terms of gain scores. Although the entire 78-items were administered, divided into three forms, only the 36-items that most directly related to course content were used for the following analysis. This was done because the GCI v1.0 covers a large range of content, much of which were unrelated to the learning targets for this course and were judged to be an inappropriate measure. Students in the unmodified course had a pre-test GCI percentage correct of 28.7 (SD=11.5, n=96) which increased to 45.3 (SD=11.8, n=84) on the post-test. After course redesign, students had a pre-test GCI percentage correct of 38.6 (SD=8.4, n=144) which increased a post-test GCI score of 48.7 (SD=7.5, n=132). Although the gains from pre-test to post-test are statistically significant, the different in post-test GCI scores between the two groups is not. This is interpreted as growth students' knowledge levels are indicative of the courses being effective, in that gain scores were equivalent in both course treatments. However, insofar as the GCI can measure, we were unable to distinguish student achievement as measured by the GCI from one style of course compared to another.

The Likert-style *Attitudes Toward Science Survey* (ATSI) was given as an end-of-class post-test to students in the pre-modified course and as a pre-test/post-test in the reformed course to compare student attitudes between the courses. For the unmodified course, the average ranking on a 5-point scale as a pre-test was 3.45 (SD=1.26, n=508).The post-test ranking was 3.49 (SD=1.05, n=101) for the unmodified course and 3.50 (SD=1.13, n=369) for the reformed course. As is commonly observed in many pre-post attitude measures conducted in introductory science survey courses, there are no statistically significant differences evident among the survey results that allows one to distinguish the success of one treatment over the other. One interpretation is that student attitudes toward learning or toward science were impacted by either treatment. However, another interpretation is that conventional Likert-style attitude surveys are not sensitive enough to observe subtle shifts in student attitudes. It is our judgement that the latter is true in this study because, interview and focus group transcripts, described in the next section, reveal that students describe the reformed course to be relevant to their lives and educationally satisfying, both of which are only infrequently observed among traditional introductory science survey courses.

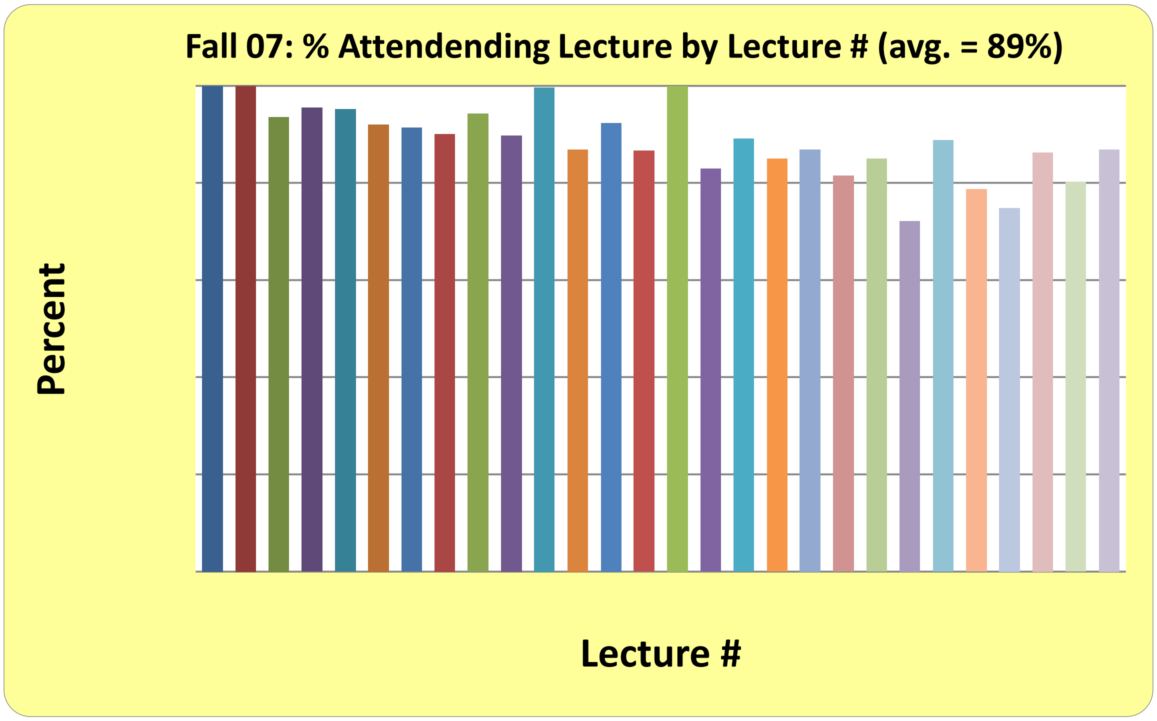

Figure 1a: Percentage of Students Who Received Attendance Points by Lecture Number in the Unmodified Course (Attendance decreased during the Semester)

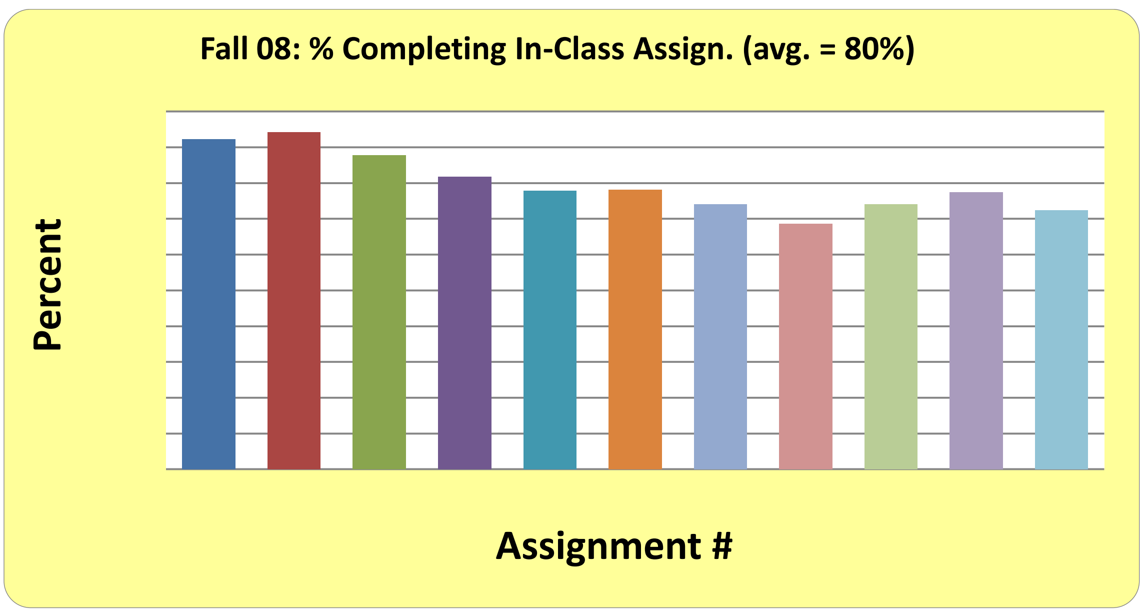

Figure 1b: Proxy for Attendance in Reformed Class, Given by the Percentage of Students Who Completed the Graded, but Unannounced, In-class Assignment by Assignment Number during the Semester (Attendance decreased during the Semester)

We compared class attendance when attendance was mandatory and monitored by sign-in sheets in the unmodified course versus the reformed course when attendance was not required but monitored by participation in graded, but unannounced, in-class activities and assignments. Figure 1a shows the percentage of students earning attendance points in the unmodified course versus week in the semester. On average, 89% of students earned attendance points during the semester. Figure 1b shows a proxy for attendance for the reformed class where attendance was not required. As a proxy, we used the percentage of students who completed in-class activities and assignments versus assignment number during the semester of the reformed course. Both figures show a similar decline in attendance during the semester. Attendance was higher when it was mandatory, but anecdotally much higher than other large-enrollment classes where attendance is not required. We find the results consistent with the qualitative data evidence, described below, that we were largely successful in creating a risk-free learning environment where students took more ownership in the process without being required to attend lecture. In addition, instructors found that students were more willing to falsify attendance in the unmodified course, where this simply required signing someone else's name on a sign-in sheet, versus completing an assignment for someone else and turning it in for a grade in the modified course.

Finally, an analysis of four common separate essay-style exam questions targeting conceptual notions of the learning targets was conducted to compare students in both the unmodified and the reformed courses. Students' written responses were analyzed holistically in terms of three categories: (1) accuracy and completeness of the response (scored as [i] grossly incomplete, [ii] somewhat incomplete or inaccurate, or [iii] mostly complete; (2) number of words (scored as [i] <50, [ii] 50-150, or [iii] >150 words); (3) numerical points assigned by graders (scored as [i] low score, [ii] medium score, or [iii] high score). We judge that these are only somewhat rough measures, but allowed the research team to obtain a general idea of what an enormous amount of written data looked like. In all categories, the student-supplied responses from the two course designs were virtually indistinguishable and no further statistical analysis was conducted. Again, in light of the contrasting qualitative data reported below, we interpret this to mean that the selected common assessment instruments and strategies had insufficient resolving power to detect important or subtle differences in student achievement or the student experience, rather than that there were no actual differences in the student experience. We acknowledge that it was much more difficult to detect differences between the treatments than we had anticipated. Indeed, all instruments available are lacking in one way or another. As an example, during this study, the GCI 1.0 planners, not the researchers who authored this paper, havenow started a major revision to the instrument in an effort to have a more community-driven and more highly sensitive instrument available to the earth science education community in the near future.

Qualitative Results

At the mid-point of the term during the redesigned semester, a team of faculty and graduate students from the University of Wyoming and Center for Astronomy &Physics Education Research (widely known as the CAPER Team) conducted individual and focus group interviews with participating faculty, graduate teaching assistants, undergraduate peer mentor instructors, and students. Focus groups were structured to be homogeneous in terms of role in the class. More than 100 participants were involved and 14 hours of transcripts were produced, in addition to the evaluators' field notes. All transcripts were inductively analyzed and reanalyzed until repeated themes emerged from the data across all transcripts. Although individual comments are viewed as valuable, this standard qualitative analysis procedure emphasizes uncovering the overarching perspectives of the group as a whole.

Four recurring themes were prominent across the extensive qualitative data collected. These notions are, listed by perceived importance to the success and value of the learning in the class, [1] structured discussion among students was meaningful; [2] the interactive nature of the course engaged students and instructors; [3] the non-adversarial nature of the course climate was critical; and [4] the purposeful instructional activities directly support metacognition. Each of these recurring and dominant themes is judged to be consistent with the perspective of creating a learner-centered environment that supports learning and students' metacognition.

<u>Theme 1: Discussion Group was Meaningful to Students.</u>

Students and instructors alike described the course as filled with repeated opportunities to absorb, process, and apply lecture information in guided and supportive settings. The weekly break-out sessions, required for all students, and co-taught by graduate teaching assistants and undergraduate peer mentor instructors, provided time-on-task to "absorb" the ideas. Further, each break-out session, which was mediated by a worksheet on which students wrote individual responses, focused on real life applications. Most students understood that the discussion sessions were not intended to provide new information, but rather that the purpose was to emphasize the important aspects of lecture. Many students agreed with the comment that, *"I'm only doing well in this course because of the break-out sessions."*

Indeed, there were a range of perceptions. The graduate teaching assistants often felt that the cognitive level required of students in the break-out sessions, and perhaps the course overall, was too low. This perspective was countered by the undergraduate peer mentors who felt that the graduate teaching assistants, who were new experts in the field, did not have a realistic assessment of what non-science majoring students needed to understand.

In the same way, some honors students, who take the class alongside all other students, but have a separate break-out session with some additional opportunities, perceived the paper-and-pencil based assignments as "busy work" toward ideas that they already understood. Many honors students agreed that, "*Break-out sessions probably help people who can't learn from lecture."*

Theme 2: The Interactive Nature of the Course Supported Learning.

All participants, instructors and students alike, understood that the underlying construction of the class required active participation during lecture. Perhaps more importantly, students understood that this course design was substantively and crucially different than other courses they were taking. For example, students understood how the concept tests and think-pair-share questions required students to actively process information rather than engaging in passive, and occasionally meaningless, "random note-taking" so often required in other classes.

Students reported that even basic pop-quizzes "on what the instructor just said" encouraged students to pay continuous attention in class. Most agreed with one student's comment that, *"If you don't pay attention you won't do well, but you should because those are easy points to help your grade."*

Students also felt that the collaborative nature of the class, both in lectures and during the required break-out sessions, helped them build a learning community and that this sense of community led to increased interaction between students in lecture. One student summarized this as, *"You can't do this kind of thing with 100 people who don't know each other."*

Theme 3: Non-adversarial Classroom Culture Supported Learning:

Many participants applauded the course instructors on the emphasis and repeated importance of clear expectations. This was most amplified when students were comparing this class to other classes they had where there was very little clarity of expectations. One student commented, *"There are no secrets in this class. They tell us over and over. If you don't know what it takes to be successful, you aren't paying attention."* This notion was consistent among students who felt that the professors and undergraduate peer mentors were focused on guiding their learning and staying on message with respect to the required learning targets. Students did not often feel the same way about the graduate teaching assistants, most of whom were required to serve in this capacity as first-year graduate students, who were reported to spend much time in telling rather than facilitating. One student said, *"GTAs tend to "spew a lot of information," "get off on self-aggrandizing," and give answers rather than guide learning."* We do not judge this to be an unusual or unexpected result, but rather common across the university setting and worthy of some targeted, although highly challenging, improvement.

Students overwhelmingly wanted to comment enthusiastically on their perceived instructors' attitudes toward the students. They felt that instructors cared about their learning, as evidenced in a number of ways. One is that the instructors' consistent and frequent use and responsiveness to formative assessments indicated to students that instructors cared about student learning. In parallel, they felt that instructors created a low-risk environment. Students repeatedly commented that the professors demonstrated respect by learning everyone's names, and that professors emailed students and greeted them by name on campus. This is judged to be highly rare as well as a highly positive effort.

Students also commented positively on the professors' efforts to make the physical environment welcoming. Students described that on-topic music welcomed them into the classroom. They also described how the professors constantly move through the lecture hall speaking to students, providing opportunities for reticent students to ask real-time questions.

Finally, students also commented on the grading structure, which is, of course, of high importance to students. There was general agreement with the comments that, *"Discussion groups provide an opportunity to improve your grade if you're a student who doesn't test well"* and that, *"Grading is fair. There are lots of chances to get points and show that you've learned something."* Examples students cited were pop quizzes, discussion, partial credit on exams, and on-line Just-in-Time quizzes on reading material before lecture. What is unusual here is that students perceive that the grading isn't an opportunity for instructors to highlight deficits in student knowledge and understanding; rather, it is seen by students as being respectful to students in helping them learn the material and earn high marks.

Theme 4: Instructional Changes Directly Support Cognition.

All participants commented on the great value in seeing a variety of teaching modalities used in the class. Students described: spoken lecture, class outline available online with computers in lecture for note taking, videos providing visualizations from multiple perspectives, and well-remembered, kinesthetic demonstrations. Students recognized that professors had a reduced focus on vocabulary. This is important because students who are struggling to apply technical jargon have less available cognitive load for processing important conceptual ideas in the class. Further, having shorter lecture periods punctuated with purposeful interactivity served to "reset" attention spans. For example, students described that think-pair-share questions shifted the nature of the class every 12-15 minutes and noted, in their own words instead of these, that this supported collaborative classroom discourse. Students seemed to understand that think-pair-share questions connect prior knowledge to new ideas, and have the ability to emphasize real-life relevancy.

Some Complex and Unresolved Issues

Although there was consistency in descriptions of the learning environment across all participants—professors, graduate teaching assistants, undergraduate peer mentors, and students—there were several issues that were not resolved by this evaluation study that are worth mentioning.

One unresolved issue is the underlying mechanism of how the in-class activities are actually impacting learning. We were unable to determine if the in-class activities are, 1) resetting students' attention spans, 2) serving as a student motivator to engage more actively in lecture because they are easy points to acquire, 3) guiding professors to refocus instruction better, or 4) gaining student buy-in because professors seem to care what is going on in the class. It is likely that there are aspects of all four possibilities involved, and resolving which (if any) is most significant would require more detailed study.

Similarly, it is unclear what exactly is going on when professors make an effort to learn students' names, and communicate with and recognize them outside of class. Is it a sign of mutual respect or is it that this action initiates the creation of a learning community among all participants? Students commented that, *"You have to show up because professors know your name and know if you aren't there,"* and that professors "*call on you by name if you don't raise your hand and engage."* Clearly, there is some sense of belonging created when professors refer to a specific student's volunteered commentary during whole class discussions. Yet, the underlying mechanism here is not clearly illuminated by this project.

Clearly, both of these issues, among others, are worthy instructional endeavors that require professors' time and energy, but exactly what is going on underneath these issues that supports instruction is not clear in this study and merits further investigation.

CONCLUSION

The combination of quantitative and qualitative data collected to evaluate this project strongly supports the contention that the project was able to meet the two primary goals. First, we were able to meet our intentional goal of reducing costs and effort by 1) reallocating faculty time from grading to teaching and 2) reallocating GTA time to undergraduate peer mentors (Figures 2a and 2b). Second, we were simultaneously able to meet the goal of increasing the degree of learner-centered teaching and student engagement because students were more participatory in lectures and spent more time interacting with instructors, undergraduate peer mentors, graduate teaching assistants, and each other. Students in the redesigned version of *A Geological Perspective* overwhelmingly report that this new system keeps them continuously engaged and helps them learn.

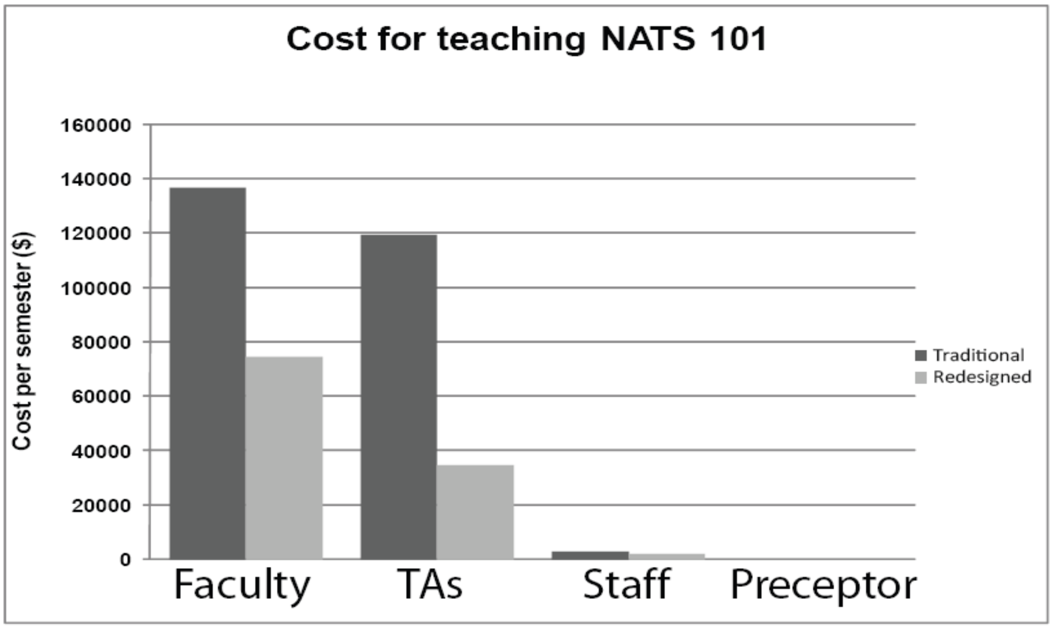

Figure 2a: Cost for Teaching NATS 101 in the Unmodified (Traditional) and Modified Versions of the Course

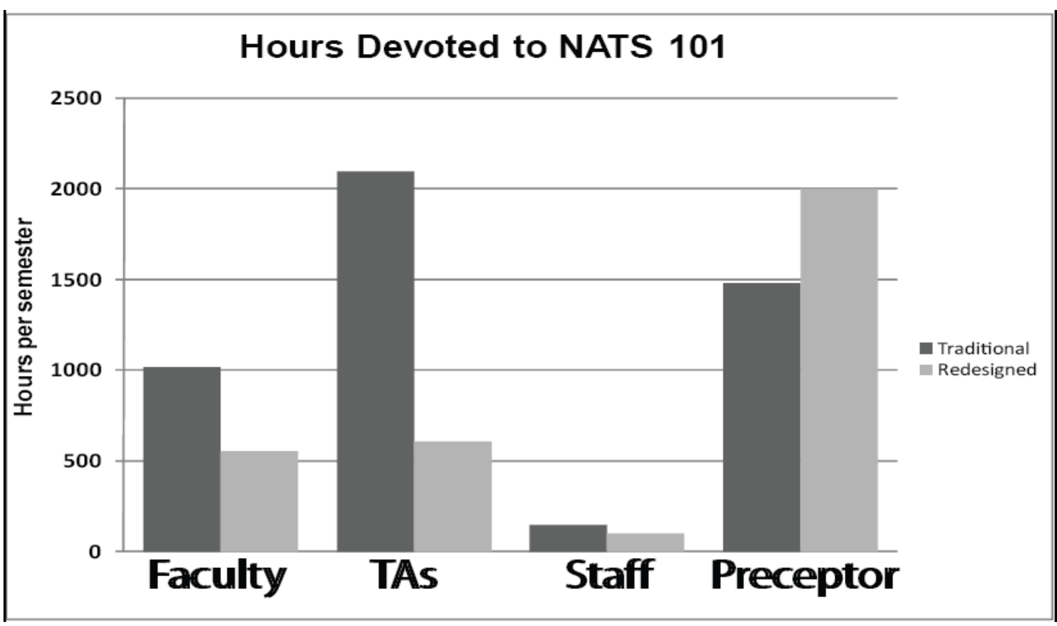

Figure 2b: Hours devoted to NATS 101 in the Unmodified (Traditional) and Modified Versions of the Course

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